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Using Autoclave Furnace to Improve Properties of Mixing an Autoclaved Aerated Concrete Waste with Window Glass Waste

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Abstract

Autoclaved aerated concrete (ACC) or thermostone is now becoming increasingly used in constructions, building and partition works due to its properties such as a highly thermal insulating concrete-based material used for both internal and external construction, light weight and large size. However, its low compressive strength and high porosity affected its use.

In this research the experimental part focused on mixing an autoclaved aerated concrete (AAC) in the form of powder with different ratios of window glass wastes powder, then study the influence of these additives onto properties of thermostone in terms of physical (absorption, porosity, density), mechanical (compressive and hardness), and thermal properties (thermal conductivity and thermal shock). The bulk density increased to about (1562Kg/m^3), porosity and water absorption have been decreased to about (39.8 %, , 23.44%) respectively with the addition ratio (30) % by weight. of glass. Also the compressive strength has been getting good result (26.27 N/mm^2) and hardness, improved (13.88) at the percentage of waste glass (30) % by weight compared to the sample with no-additive. Finally, thermal conductivity with the result (0.5311 watt/m.°c) at the same percentage of waste glass, while thermal shock showed well result with the additives (10, 20, 30) % by weight at temperature 250 °C for 1 h, but failed at temperature of 350 °C for the same time.

Key Words: Autoclaved aerated concrete (AAC), Glass, Mechanical Properties, Thermal Properties.

الخلاصة

إن كتل الخرسانة الخلوية أو ما يسمى بالثرمستون أصبح له استخدامات كثيرة في السنوات الأخيرة في عمليات البناء والإنشاءات والتقطيع في الدور و العمارات نظرا لتميزه بمواصفات مثل العزل الحراري الخاص للاستخدام في البنايات من الداخل والخارج، خفة وزنه و كبر حجم المقاطع المستخدمة. ومع ذلك فان له مقاومة انضغاط قليلة ومسامية قليلة عند استخدامه.

في هذا البحث تركزت الدراسة العملية على خلط مسحوق الخرسانة الخلوية مع نسب مختلفة من الزجاج المتبقي حيث تم دراسة تأثير هذه النسب من الزجاج على خواص الثرمستون والتي تشمل الخواص الفيزيائية (الكثافة، الامتصاصية، المسامية) ، الخواص الميكانيكية (مقاومة الانضغاط، الصلادة)، والخواص الحرارية (التوصيلية الحرارية، الصدمة الحرارية). الكثافة تزداد الى (1583 كغم/م3)، والامتصاصية تنخفض الى (23.44 %) والمسامية ايضا تنخفض الى (% 39.8) عند نسبة وزنية (30)% من الزجاج المضاف. ايضا مقاومة الانضغاط تزداد الى (26.27 نيوتن/ملم2) والصلادة تتحسن الى (.13.88) عند نسبة وزنية من الزجاج المضاف (30)% . وأخيرا التوصيلية الحرارية تبين تحسن جيد (0.5311 واط/ م. م°) عند نفس النسبة من الزجاج المضاف، في حين ان الصدمة الحرارية تبين نتائج جيدة عند الاضافات (10، 20، 30) % عند درجة حرارة (250 م°) لكن حصل الفشل عند درجة حرارة (350 م°) لنفس الفترة الزمنية.

الكلمات المفتاحية: الثرمستون، الزجاج، الخواص الميكانيكية، الخواص الحرارية.

1. Introduction

Autoclaved aerated concrete (AAC) or thermostone is a construction material that is factory-made and available to the user in blocks and precast units for walls, floors, and roofs. Blocks for laying in mortar or glue are produced without any reinforcement (Comite Euro-International du Beton, 1978). It has gained widespread use in many areas of the world including Europe, South America, the Middle East, and the Far East. In brief, autoclaved aerated concrete is a porous, lightweight concrete whose cellular structure is generally obtained through an in situ gas-producing chemical reaction of sand and cement slurry. It generally contains no coarse material. Subsequent autoclaving of the material at high temperature and pressure imparts strength, dimensional stability, and other properties of the hardened final product. The autoclaved aerated concrete building material is obtained as the result of a reaction between the binder containing calcium oxide and a silica component cured in an autoclave (Tabak, 1974). The important properties of autoclaved aerated concrete are present to a larger degree in cellular concretes than others (Leitch, 1980). autoclaved aerated concrete is the combination of relatively low thermal conductivity, and load bearing capacity for use in structural applications (Frey and Briesemann, 1985; Bave,1983; Kohler, 1983)which has a low density, high strength-to weight ratio, nailability, fire resistance, good thermal resistance, and high sound insulation value (Autoclaved Aerated Concrete," Building Digest 86,1970; Korovkevich, 1968). The thermal conductivity properties offer potential to conserve energy by reducing building heating and cooling fuel consumption. The properties of cellular concrete such as strength, creep, shrinkage, permeability, and diffusivity, are linked to its porosity and pore size distribution. Higher porosity of aerated concrete has been confirmed to be the result of raising in macropore volume (Alexanderson, 1979).

physical, mechanical tests, chemical analysis, and X-ray diffraction technique were investigated by A. A. Hussain. The results showed that the minimum reaction temperature was 43 or more to make the complete reaction (Hydrogen bubbles formation) between lime (CaO), water ,and aluminum powder while hydration temperature less than 40 °C no observed reaction took place. It was found that the suitable aluminum powder diameter was (50-100) µm to be for best product properties. Excessive expansion in both green and autoclaved products obtain by X- Ray diffraction that appear because of detrimental components causing moisture spots. So get a product fulfills the specification requirements .by increasing autoclaving period from 10 to 14 hours or adding up to 5% lime aggregate (Ali, 2012).

Thermal properties of three commercial types of AAC, with different bulk densities and compressive strengths, were studied by M. Jerman *et.al.*,. It was found that as the bulk density increased, the open porosity decreased as well. Moreover, water absorption and apparent moisture diffusivity decreased with an increasing bulk density. Water transport was the fastest in the sample with higher porosity. In addition, it was observed that thermal conductivity largely depended on temperature. Furthermore, all AAC samples demonstrated isotropic with respect to water and water vapor transport (Jerman et.al., 2013).

R.R. Krishnamoorthy, j. Zujip were replaced the crush recycle with the fine aggregate and studied the factors that affected on the thermal conductivity. The results showed that the thermal conductivity will increase with the increasing of water cement ratio due to the rising in content of aggregate that is effecting on the thermal conductivity of the specimen which is excess with having been the moisture. It excessed with the evolution of crushed recycled glass which has a good and accurate potential in the construction industry to supply good insulation in concrete, essential for use in equatorial county and to decreasing energy costs. (Krishnamoorthy and Zujip, 2013).

Shilpa Raju, Dr. P. R. Kumar was studied the addition of powder glass to the concrete and show that the workability decrease as the percentage of glass powder increase, by using super plasticizer that be substantial to preserve workability with limited water cement ratio. When the glass powder increase up to 20% the compressive strength increases and to the further side 20% strength less. Also the increasing in percentage of glass powder up to 20% replacement and 20% strength fall down the flexural strength also increases. So it can be replace the waste glass powder in concrete with the cement. Excellent filler and sufficient pozzolonic properties of fine ground glass can be used as a partial cement replacement.(Shilpa and Kumar, 2014).

Pawel and Jan, studied the fabrication of autoclaved aerated concrete by using glass additives. It can be manufactured autoclaved aerated concrete with varied types of glass cullet. The autoclaved aerated concrete with additives of CRT glass and cullet has a compressive strength identical to the predication sample, the main reason of glass powder that has no influence on the specific hydration products and no cause harm compounds, the compressive strength improvement the combination of glass powder, using glass in the production of AAC give fantastic method of the waste exploitation. (Paweł *et.al.*, 2015).

This study helped in saving the environment and support the government by finding the solutions that regarding the disposal to landfills of glass waste materials and prolonged good information to the contractors and developers for getting better the methods of construction industry that meet recycling goals for suffered good product performance and services by using glass.

2. Experimental Part

2.1 The materials

2.1.1. Preparation of waste Cellular Concrete (thermostone) powder

Pieces of waste thermostat were taken which cleaned by soft brush, then crushed into small pieces and ground by electrical mill.

After that, the ground thermostone waste powder was sieved. The powder, which passed through (300 micron) sieve was taken. The chemical analysis of a sample of thermostone material is shown in table (1) according to the analysis from the labs of the thermostone Karbala company.

2.1.2. Preparation of waste glass powder

It includes taking the glass windows and crushed it into small pieces with a manual hammer, then ground by electrical mill. The ground glass powder, sieved by using the mechanical sieve Shaker (Babylon University- college of Engineering Materials to determine the particle size distribution according to ASTM (C136). The particle size distribution and requirements of the applicable specification can be controlled by using perfect grain size. Also the relationships between porosity and packing will be improved by using these supply gradations. It is tested to determine the grading, the sieve number 300 micrometer for milled thermostone and 160 micrometer for milled glass .The powder which passed through sieve was taken. After milling processes, test the glass powder by using x-ray diffraction (XRD) test.

2.1.2.1. X-Ray Diffraction (XRD)

It is a rapid analytical technique, firstly used for consistency the phase of crystalline materials and also can supply notification on unite cell dimensions. It is created in cathode ray tube by heating a filament to generate electrons accelerator toward the target by applying high voltage. The interaction between the incident rays and sample produces constructive interference and diffracted ray when conditions satisfy the Bragg law [Bragg Law].

$$n\lambda = 2d \sin\theta$$

Where θ, is the angle of incidence of the x=ray. λ ,is the wave length of the X-rays used and d is the spacing between atom layer. The apparatus of x-ray diffraction (XRD) type (Shimadzu 6000, Japan) which is available at the Babylon University / College of Materials Engineering – Department of Ceramics and Building Materials was used to characterize the structure of glass.

2.1.3. Preparation of samples

2.1.3.1. Standard samples

An amount of thermostone powder was taken and mixed with (3 cc) of PVA **(**It is a binder material used to facilitate the mixing of materials and the compression process**) ,** after that it put in cleaned and oiled molds with radius (30 mm).

The thermeston powder were pressed by using pressing machine that is available at the Babylon University / College of Materials Engineering – Department of Ceramics and Building Materials as shown in figure (4) with the applied load (1MPA), then drying the specimens in drying oven which is available at the Babylon University / College of Materials Engineering – Department of Ceramics and Building Materials at 110 □ C for 24 hours after this put the specimen in an autoclave furnace that is available at the Alforat Karbala company as shown in figure (5) below, and coordinated in such a way that the pressurized steam circumfluent each specimen for curing which done at a pressure 10 Atmosphere, temperature 180 ° C for 12 hours.

2.1.3.2. Composite Samples

Quantity of thermostone powder was weighted, with utilization waste glass powder according to specified addition percent that shown in table (2), the same procedure was used as the above to prepare the composite samples by mixing the two powders (thermostone and glass) for 4 hours to ensure good homogenous, then a (3 cc) of PVA was added to each sample.

Putting the mixture in cleaned and oiled molds with the similar radius (30 mm). Then the specimens compressed and drying under the same status, after this put the specimen in autoclave furnace and arranged in such a way by using the same conditions that used for preparing standard samples . The final product will be tested by doing several tests, like compressive strength, hardness, density, porosity, absorption, thermal conductivity and thermal shock.

3. Result and Discussion

3.1. XRD analysis of glass

The figure (1) shows the phase of the XRD test for glass is non-homogenous structure. So the glass sample can be seen amorphous and no diffraction peaks are observed due to its behavior .

3.2. Physical properties

3.2.1 Bulk density

The bulk density of standard and composite materials that measured according to American standard (ASTM C1693-11), shown in the figure (2), It was noticed that density increased by increasing the proportion of the glass addition. The increment is (3.84, 4.65 and 5.47) % of standard samples for (10, 20, and 30) % of glass respectively. This behavior was expected due to the decline in porosity and absorption as mentioned above. The increase in the density is the main reason behind the increase in the mechanical properties. The following equation used for determining the density of samples according to:

$$\mathbf{B = D / V}$$

Where B is Bulk density, D is dry weight of the samples and V is the exterior volume of the samples.

3.2.2. Porosity

The results show that the porosity decrease with increasing of glass addition, due to glass fusing during the autoclaving process, which helps fill the pores of thermostat powder. Figure (3) shows the relation between porosity with glass addition. Note that the test was conducted according to standard (ASTM C373). and could be compute by using the following equation:

$$P(\%) = \frac{M-D}{M-S} * 100$$

Where:

P = porosity
M = Saturated weight to the specimen (g) after 24h in water
D = Dry weight of the specimen (g).
S = Suspended weight of the specimen (g).

3.2.3. Water Absorption Measurements

The outcomes indicate that the water absorption reduction with rising of glass addition, by mixing the glass during the autoclave that is anticipated due to its low porosity. Figure (4) shows the relation between water absorption and glass addition. This behavior was conducted according to standard (ASTM C1693-11), and could be fined by following equation :

$$A(\%) = \frac{M-D}{D} * 100$$

Where:

A = absorption (%)
M = Saturated weight to the specimen (g) after 24h in water
D = Dry weight of the specimen (g).

3.3. Mechanical properties

3.3.1. Compression Strength

The compression strength values increase. Figure (5) shows the results of compression strength , notice that The compression strength improved with increasing of glass percent, this is because the degree of temperature, high pressure and long time of the autoclaving process causing smelted glass and fills the pores in the material leads to increase density, and it increases the adhesion strength between the components of composite materials, which reflects on compressive strength. Note that This test is according to (ASTM C39/39M-03). The following equation used for determining the compressive strength :

$$F = \frac{P}{A}$$

f: compressive strength of the specimen (KN/mm^2)

P: maximum load (KN)

A: cross section area of the specimen in (mm^2).

3.3.2. Hardness

Hardness improved significantly with the augmentation of the glass percentage, which means material's resistance to deformation by wear, cut, scratching, penetration and indentation. This improvement belongs to good strength bond between the parts of composite materials. The results of the samples in the Vickers hardness test are shown figure (6) shows the relation between glass addition and Vickers's hardness .The increase in the hardness due to the addition of glass percentage. Vickers hardness (Hv) is expressed from the relation below (Revankar, 2003):

$$\mathbf{Hv = 1.8544(P/d^2)}$$

Where P is the load applied in gram force and d is the average diagonal length of the indentation impression measured in μm .

3.4 Thermal properties

3.4.1. Thermal conductivity

Thermal insulation is very important and an essential requirement in buildings. And it is considered one of the most important properties of lightweight concrete. notice that in figure (7) the thermal conductivity increased with increasing the glass percentage, this increment due to decreasing porosity by glass fused which have thermal conductivity higher than air . From the principle of thermal conductivity of materials it can be concluded that the thermal conductivity is as intrinsic properties that depend on the atomic structure of materials.

3.4.2.Thermal shock

Table (3) show the result of the duration of heating and cooling of the standard and composite samples, then the samples were put in electrical heater for one hour and directly cooling in water. It has been shown that the slandered sample failed at 250°C while the other composite material give a good result at the same temperature and have high thermal shock resistance compare with the slandered sample.

Conclusion

In this study the density increased with increasing glass addition respectively (10, 20, 30) % compared to the standard samples 0% of glass addition, and the porosity of a composite material reduced by addition the glass which leads to reduction in absorption compared to the standard sample. Compression strength and Vickers's hardness, also improved with increasing glass addition by the same percentage. Finally the thermal conductivity increased for less porosity with increasing ratio of glass, while thermal shock resistance give a good result at 250 °C for all ratio of glass additives (10, 20, 30) %, notice that the standard and composite samples are less than normal concrete to one-third of the quantity ,and little higher than thermostone thermal conductivity.

It can produce a new building material which used in many applications that thermostone could not use such high moisture places and high load like loaded walls. Economically appropriate and reduces environmental pollution because the materials used are of waste.

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Fig. (6):Relation between Vickers's hardness and glass addition.
Fig. (7):Relation between thermal conductivity and glass addition.

Table (1): The chemical composition of thermostone

Materials	(Wt)%
Sand	32.5
Limestone	32.5
Cement	20
Water +Chemicals	10
Aluminum	5

Table(2) The percent of thermostone and glass

Samples	Thermostone % (by weight)	Glass % (by weight)
A	100	0
B	90	10
C	80	20
D	70	30

Table (3) The result of thermal shock tests

Sample	Glass addition %	*Duration of heating and cooling*	*State of samples*
A	0	25 °C $\xrightarrow{\text{for 1 h}}$ 150 °C $\xrightarrow{\text{directly}}$ 15°C	Good
		25 °C $\xrightarrow{\text{for 1 h}}$ 250 °C $\xrightarrow{\text{directly}}$ 15°C	Failed
		25 °C $\xrightarrow{\text{for 1 h}}$ 350 °C $\xrightarrow{\text{directly}}$ 15°C	Failed
B	10	25 °C $\xrightarrow{\text{for 1 h}}$ 150 °C $\xrightarrow{\text{directly}}$ 15°C	Good
		25 °C $\xrightarrow{\text{for 1 h}}$ 250 °C $\xrightarrow{\text{directly}}$ 15°C	Good
		25 °C $\xrightarrow{\text{for 1 h}}$ 350 °C $\xrightarrow{\text{directly}}$ 15°C	Failed
C	20	25 °C $\xrightarrow{\text{for 1 h}}$ 150 °C $\xrightarrow{\text{directly}}$ 15°C	Good
		25 °C $\xrightarrow{\text{for 1 h}}$ 250 °C $\xrightarrow{\text{directly}}$ 15°C	Good
		25 °C $\xrightarrow{\text{for 1 h}}$ 350 °C $\xrightarrow{\text{directly}}$ 15°C	Failed
D	30	25 °C $\xrightarrow{\text{for 1 h}}$ 150 °C $\xrightarrow{\text{directly}}$ 15°C	Good
		25 °C $\xrightarrow{\text{for 1 h}}$ 250 °C $\xrightarrow{\text{directly}}$ 15°C	Good
		25 °C $\xrightarrow{\text{for 1 h}}$ 350 °C $\xrightarrow{\text{directly}}$ 15°C	Failed

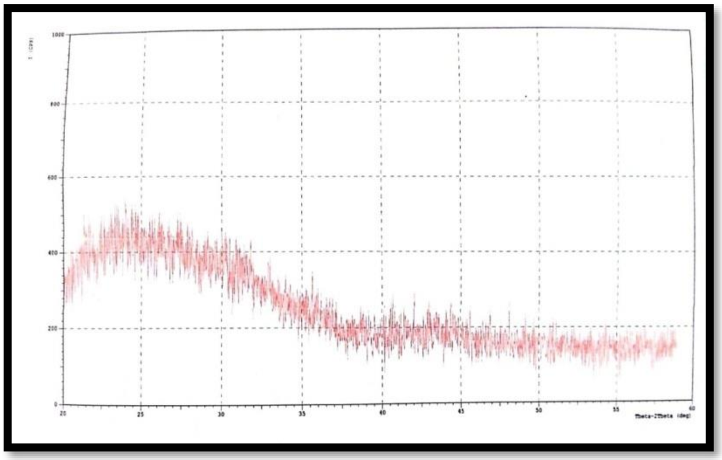

Fig.(1): XRD of glass

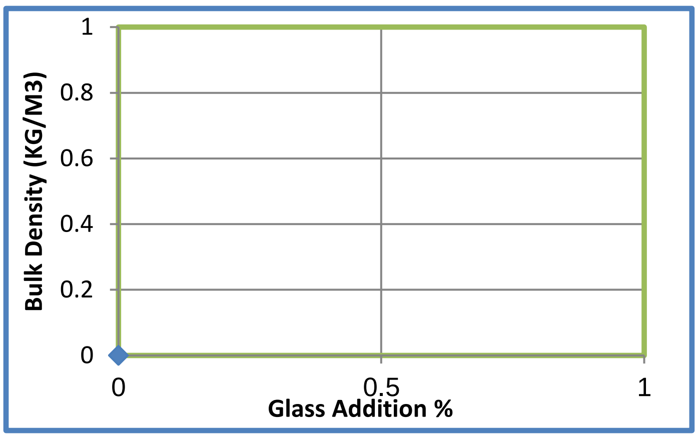

Fig.(2): Relation between bulk density and glass addition.

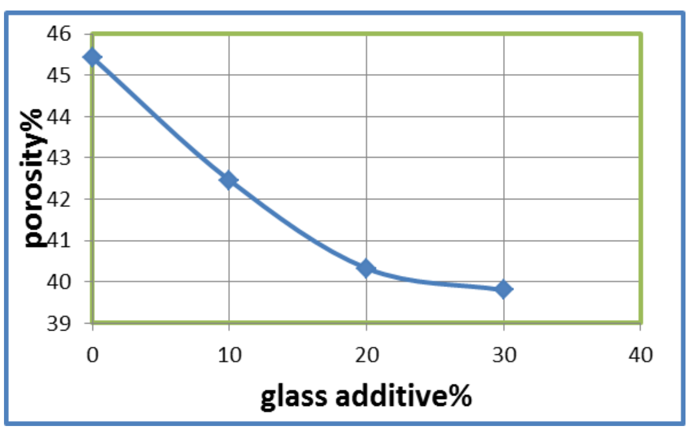

Fig. (3): relation between porosity and glass addition

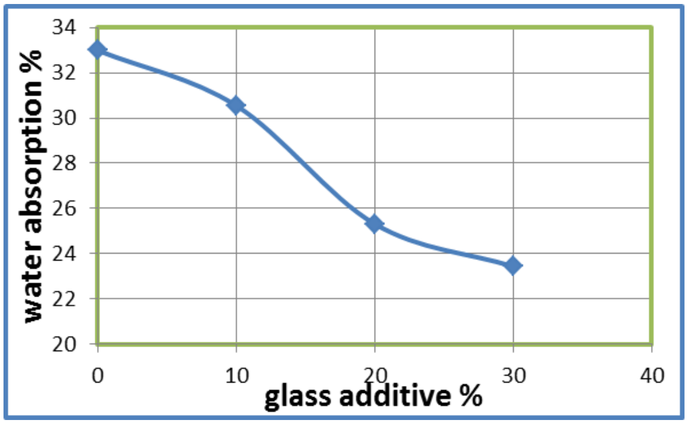

Fig. (4): Relation between absorption and glass addition

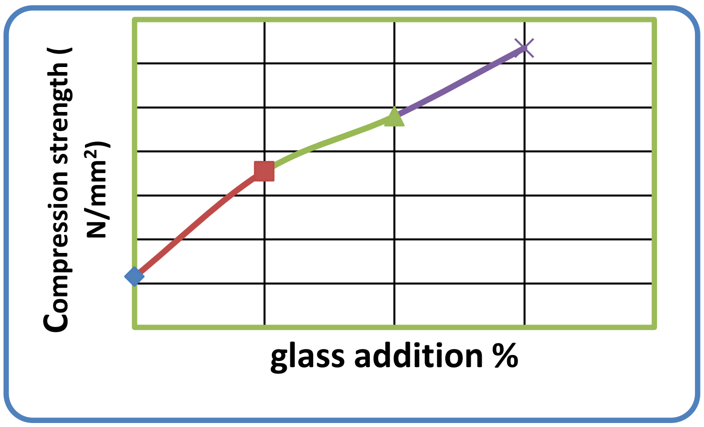

Fig. (5): Relation between compression strength and glass addition

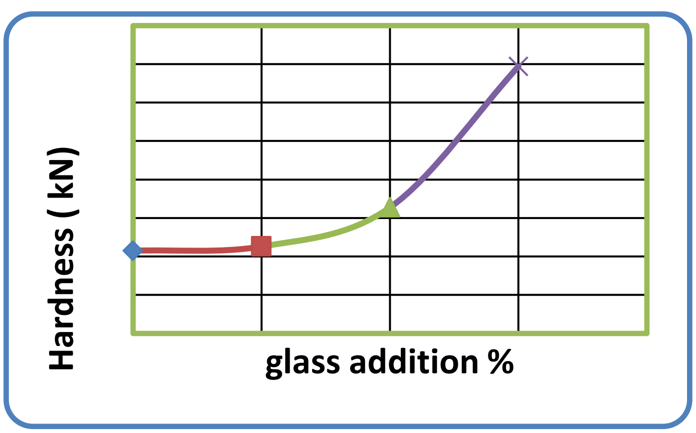

Fig. (6): Relation between Vickers's hardness and glass addition

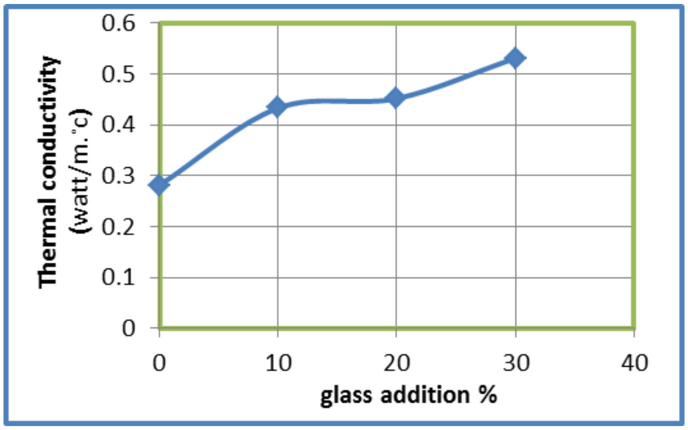

Fig. (7): Relation between thermal conductivity and glass addition